Ship-based and satellite remote sensing cloud retrievals consistency and the quantification of aerosol-cloud interactions

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1. Introduction

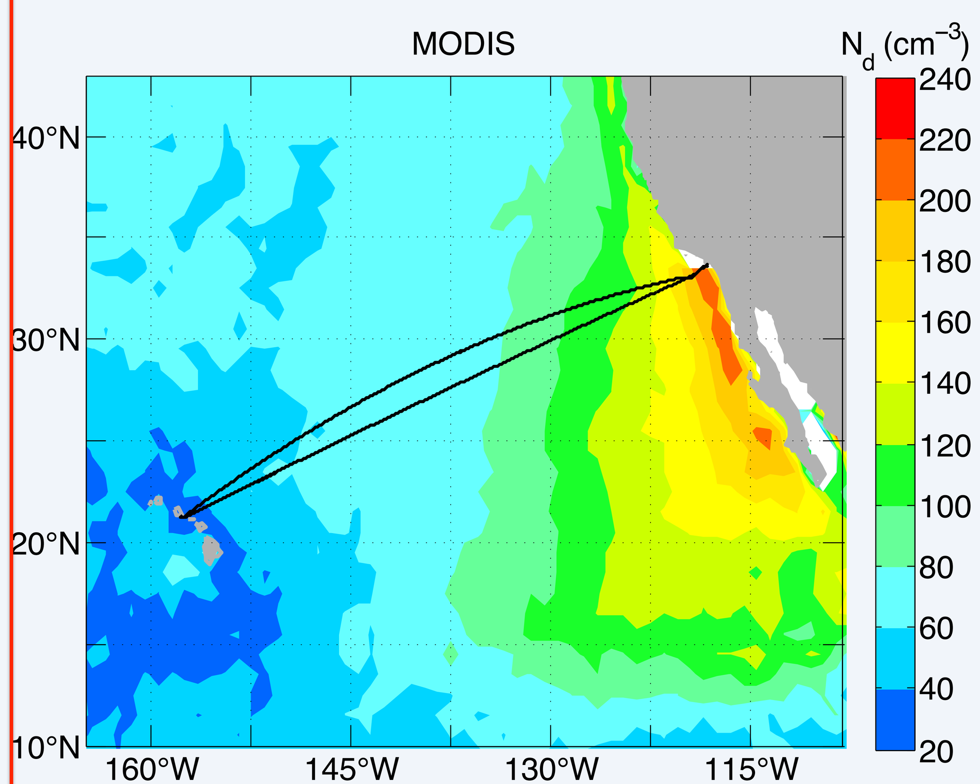


Figure 1: MODIS climatology of cloud droplet number concentration (N_d) over the Northeast Pacific. Black solid lines represent the ship transects during MAGIC.

- The northeast **(NE) Pacific** has been identified as one of the subtropical cloud regimes where microphysical variability driven by aerosols can strongly modify the albedo of the cloud deck [e.g., *Painemal and Minnis*, 2012]. Satellite-derived cloud droplet number concentration in this region has a notorious westward decrease (Fig. 1).

- The deployment of the second AMF on the container ship, Horizon Spirit, during **MAGIC campaign** presents a unique opportunity to investigate the aerosol variability and cloud-aerosol interactions in marine clouds [*Lewis and Teixeira*, 2015].

- We evaluate the consistency among different remotely sensed cloud and aerosol properties and analyze their applicability to the quantification of aerosol-cloud interactions during MAGIC.

2. Dataset

Ship-based observations

Liquid water path from a 3-channel microwave radiometer [*Cadeddu et al., 2013*].
Cloud optical thickness (τ) and effective radius (r_e) from a sun-photometer [*Chiu et al., 2012*].

Aerosols: CCN probe, aerosol size distribution from an Ultra-High Sensitivity Aerosol Spectrometer (UHSAS), aerosol scattering and absorption coefficient from a nephelometer, and a particle soot absorption photometer (PSAP), aerosol backscatter from a high spectral resolution lidar (HSRL)

Satellite data

τ, r_e, and LWP from the MOderate resolution Imaging Spectroradiometer (MODIS) and geostationary GOES-15 Imager using CERES edition 4 algorithms. MODIS 1km and GOES 4km pixel resolution averaged to a 20 km grid.

3. Results

3.1. Ship-based vs satellite cloud properties

- Collocated satellite LWP and τ agree well with their hourly-mean ship-based counterparts (Fig. 2a and b, respectively).
- Cloud droplet number concentration (N_d) assuming adiabaticity [e.g. *Painemal and Zuidema*, 2013]. This allows to calculae N_d in terms of (LWP, τ), or (LWP, r_e).
- Satellite vs ship-based comparison is best when N_d is derived from τ and LWP. τ is typically a more robust ground-based retrieval than r_e [e.g. *Chiu et al.* 2012].

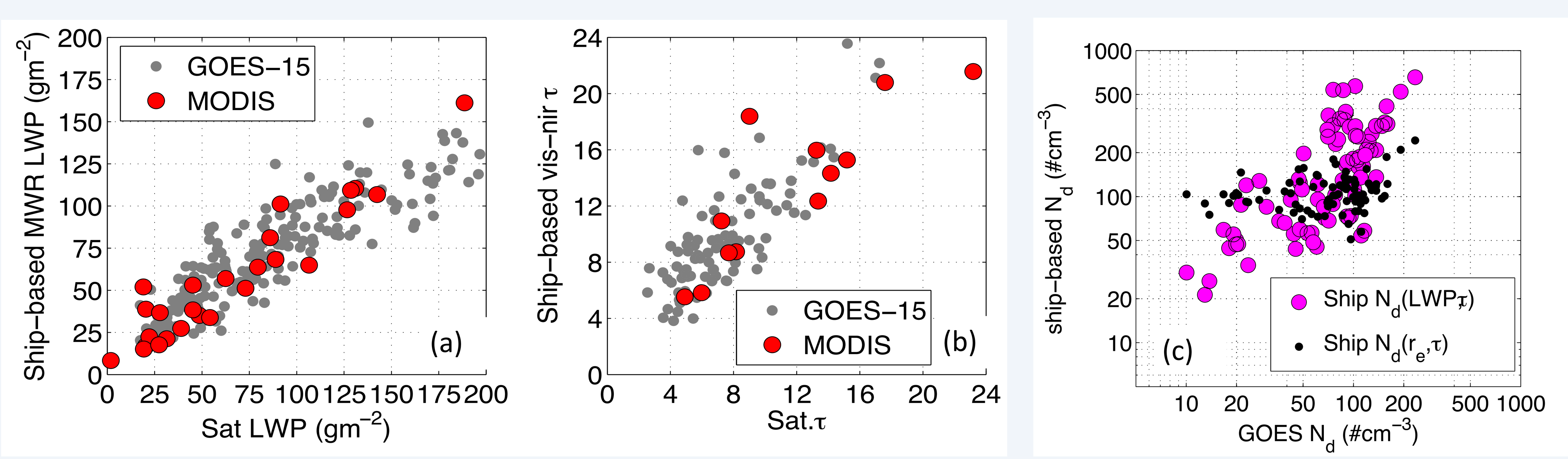


Figure 2: Scatterplot between GOES-15 (gray) and MODIS (red) satellite retrievals against their ship-based counterparts for a) LWP and b) τ. c) comparison between ship-based and satellite GOES-15 N_d.

3.2. Aerosol proxies

We investigate whether aerosol accumulation mode (N_a, UHSAS), **dry** scattering (σ_{scatt}, nephelometer), and extinction coefficients (σ_{ext}, nephelometer+PSAP) can be used as CCN proxies (0.4% of supersaturation).

- Accumulation mode reproduces the CCN variability (*Fig. 3a*)
- σ_{scatt} and σ_{ext} correlate well with CCN (r=0.9), with a modest effect of absorption (Fig. 3b-c).
- York linear fit calculations assuming varying errors (δ) in σ_{scatt} and σ_{ext} and a fixed error in CCN of 10% yield logarithmic slopes between 0.62-0.78, consistent with *Shinozuka et al.* [2015].

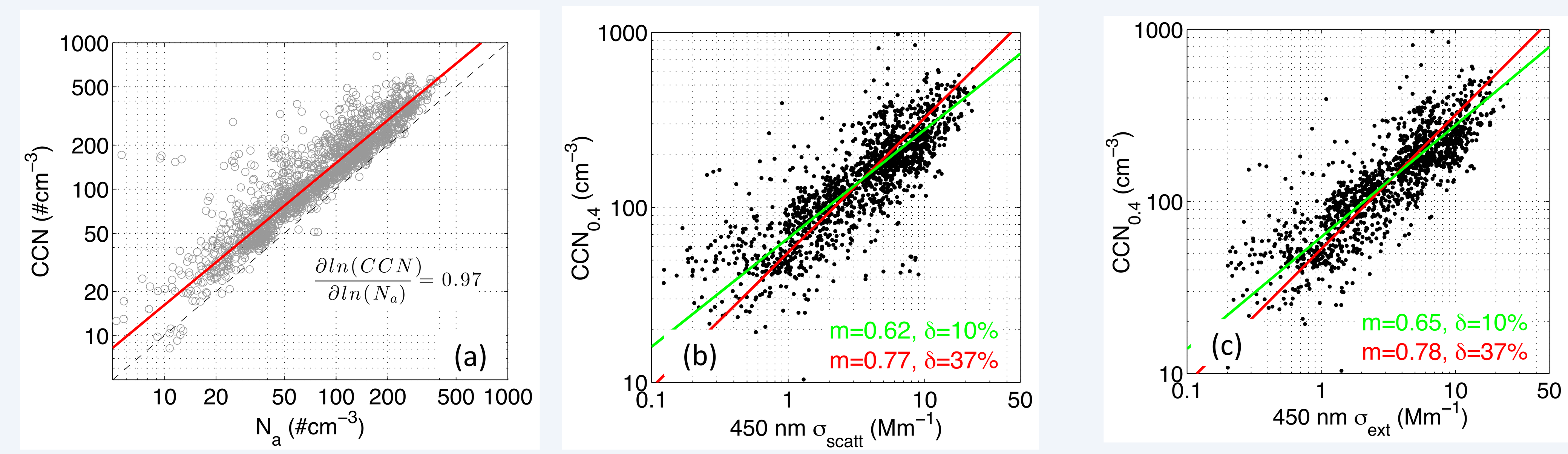


Figure 3: Scatterplot between CCN and a) accumulation mode aerosol N_a, (b) aerosol scattering σ_{scatt}, and (c) extinction coefficient σ_{ext}. Green and red lines in (b) and (c) are the linear regression using the York method with errors in σ_{scatt} and σ_{ext} of 10% and 37% (10 min standard deviation).

3.3. Aerosol-Cloud co-variability

We used a simple metric for quantifying aerosol cloud interactions (ACI): $ACI = \frac{\partial \ln (N_d)}{\partial \ln (\alpha)}$, with α denoting surface observations of **CCN** or **accumulation mode concentration (N_a)**:

Satellite-based N_d vs ship-based CCN | **Ship-based N_d vs ship-based CCN** | **Ship-based N_d vs ship-based N_a**

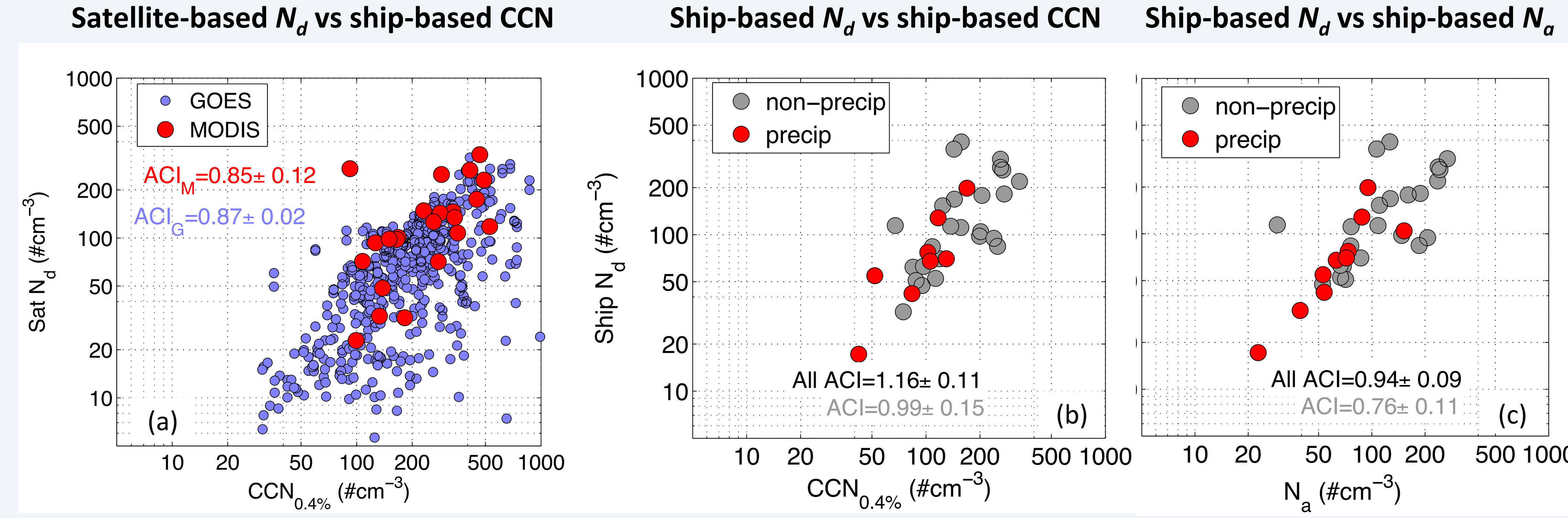
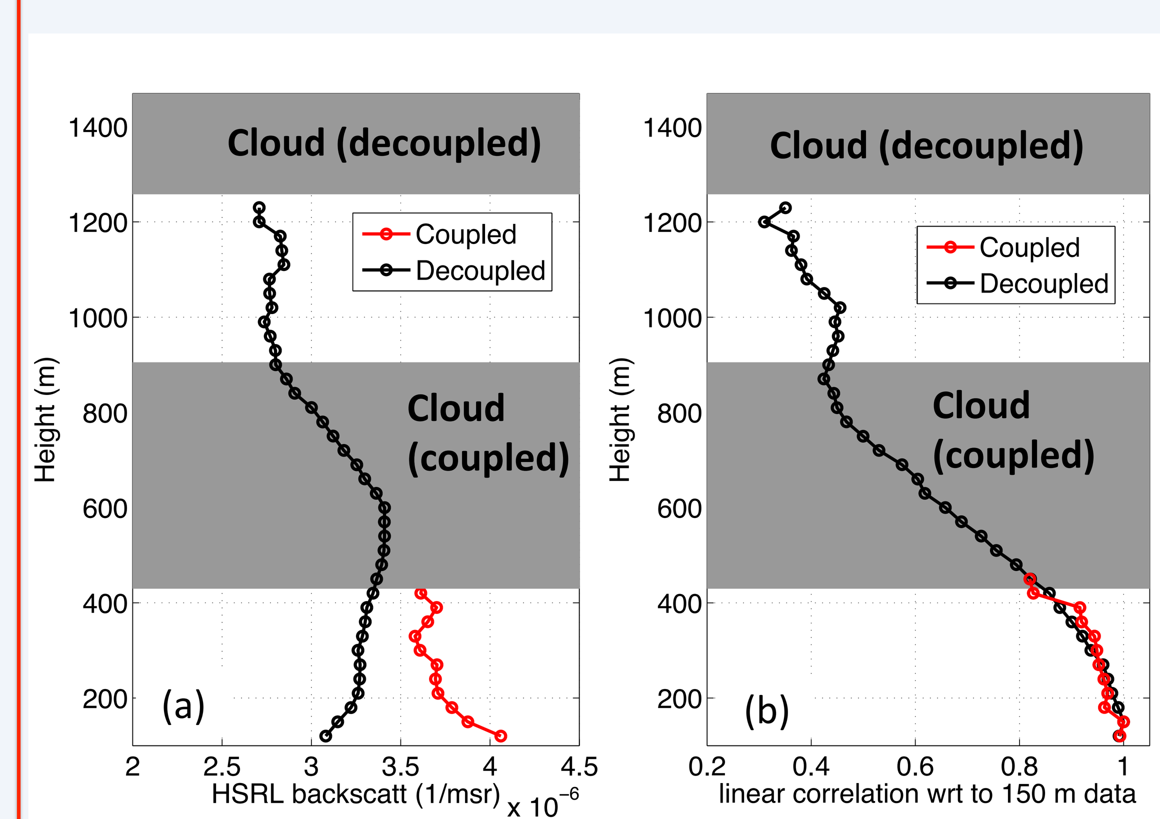


Figure 4: CCN and N_a vs satellite-based and ship-based N_d (a and b-c, respectively).

3.4. Aerosol vertical structure: preliminary HSRL analysis



- HSRL particle backscatter was used to investigate the aerosol vertical structure during July 2013.
- **Coupled and decoupled** samples: cloud base height and lifting condensation level difference **<200 m** and **> 400**, respectively.
- Decoupled boundary layers are deeper and backscatter decreases near the cloud base (Fig. 5a).
- Strong correlations between backscatter at 150 m and those from levels below 400 m. Reduced correlation near the cloud base for the decoupled profile (Fig. 5b).

Figure 5: a) HSRL mean particulate backscatter, b) correlation between the HSRL backscatter at 150 m at those from level aloft. Red and black are coupled and decoupled cases, respectively.

4. Concluding Remarks

- Agreement between satellite and ship-based cloud properties yield consistent N_d-*CCN* relationship.
- Accumulation mode aerosols and extinction coefficients are adequate CCN proxies over this region. Extinction-*CCN* slope <1.0.
- Strong aerosol-cloud interactions consistent with aircraft observations in other marine low clouds regimes.
- Results point to deficiencies in previous satellite-based estimates.
- Information about the aerosol vertical structure might be important in deep (decoupled) boundary layers.

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